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RESEARCH REVIEW

Hydrogen Engine Evaluation Using MATT
Researchers devise new combustion strategies for hydrogen engines using the Modular Automotive Technology Testbed. **Page 2**

Argonne Is Full of Energy (Research)
Argonne produces some of the most cited and influential scientific papers in the field. **Page 3**

This Omnivore Likes a Variety of Fuels, not Foods
Argonne's omnivorous engine can take down any blend of gasoline, ethanol, butanol, and other types of spark-ignited fuel. **Page 4**

New Tribology Center Opens its Doors
Research done at the Illinois Center for Advanced Tribology will increase knowledge about interacting surfaces. **Page 6**

Facility Spotlight: The Tribology Center's CemeCon
Argonne's CemeCon system is used to deposit new and novel coatings that enhance the durability and efficiency of transportation systems. **Page 7**

Real-World Temperature Effects on Plug-in Hybrid Electric Vehicles
Researchers are examining PHEV experimental test data to discover the thermal effects on fuel efficiency. **Page 8**

GREET 1.8c Available Now
On March 23, 2009, the newest version of GREET was released by Argonne. **Page 9**

Argonne Engineer Helps Assess NASA's Energy Storage Capabilities
Researcher Jim Miller finds that Argonne's battery research could also benefit NASA. **Page 10**

Drivetrain Electrification Components Also 'Drive' Price
Components used in hybrid and electric vehicles can improve efficiency and lower manufacturing costs. **Page 11**

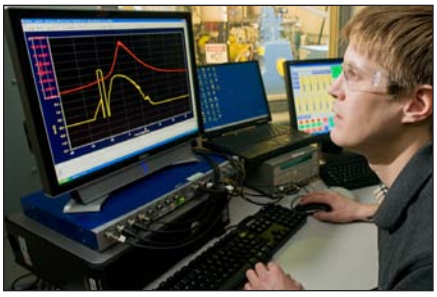
Student Innovators Driven by the Environment
Student engineers in EcoCAR: The NeXt Challenge unveil their vehicle architectures. **Page 12**

Water Use in the Production of Biofuels and Gasoline
Researchers study water use in the production of energy feedstocks and fuels. **Page 13**

IN THE NEWS Page 14

FASTRAX Page 14

PUTTING ARGONNE'S RESOURCES TO WORK FOR YOU Page 16



U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory
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Hydrogen Engine Evaluation Using MATT

Through the use of an Argonne-developed test platform, researchers have devised new combustion strategies for hydrogen-powered vehicles that come one step closer to energy-efficient, cost-effective travel that emits no greenhouse gases or other pollutants.

Unlike hydrogen fuel cells, which convert hydrogen to electricity through an electrochemical reaction that yields no on-board pollutants, hydrogen internal combustion engines can produce nitrogen oxides (NO_x). Due to the wide flammability range of hydrogen, a hydrogen engine can run at extremely high air-fuel ratios. All else being equal, the leanest combustion allows the engine to run efficiently and reduces emissions. However, the leaner combustion dramatically reduces the power output of the engine.

Using the Modular Automotive Technology Testbed (MATT) (Figure 1), Henning Lohse-Busch and his colleagues in Argonne's Transportation Technology Research & Development Center (TTRDC) have determined that varying the air-hydrogen ratio can reduce the trade-off between fuel economy, low-NO_x emissions and power for these engines.

Figure 1: In-vehicle testing of the hydrogen engine on MATT.

"With a constant air-fuel ratio combustion strategy, you have to sacrifice fuel economy, high performance or low emissions," Lohse-Busch said. "The variable air-fuel ratio combustion strategy that we developed for hydrogen engines resulted in the best fuel economy while achieving very low emissions even without an exhaust after-treatment system." (Figures 2 and 3)

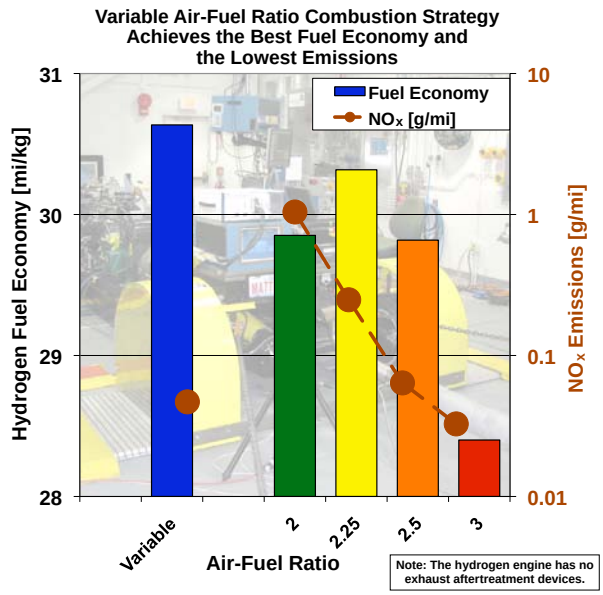

Figure 2: Fuel economy and emissions on hot start UDDS.

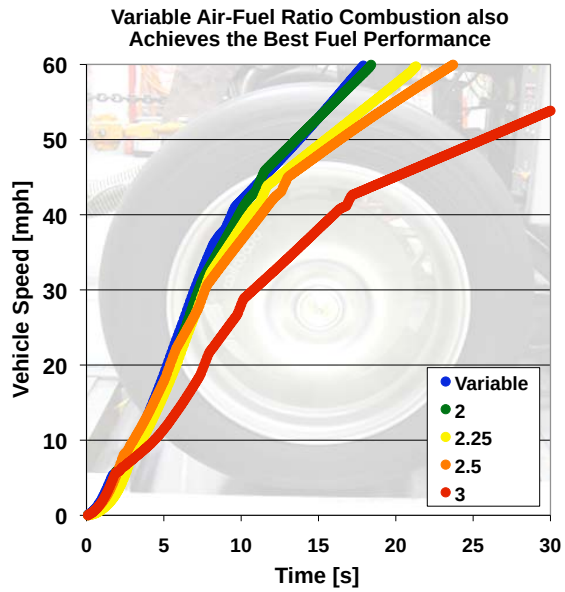

Figure 3: Performance: 0 to 60 mph acceleration.

MATT is an Erector Set™-like platform for automotive powertrains in which engineers can swap in and out different engines, transmissions and other core powertrain components. It has given Argonne researchers the ability to test a 4-cylinder hydrogen engine on standard drive cycles.

"One of the major advantages of MATT is that it allows us to separately test and benchmark individual components as they work in a system," said Lohse-Busch.

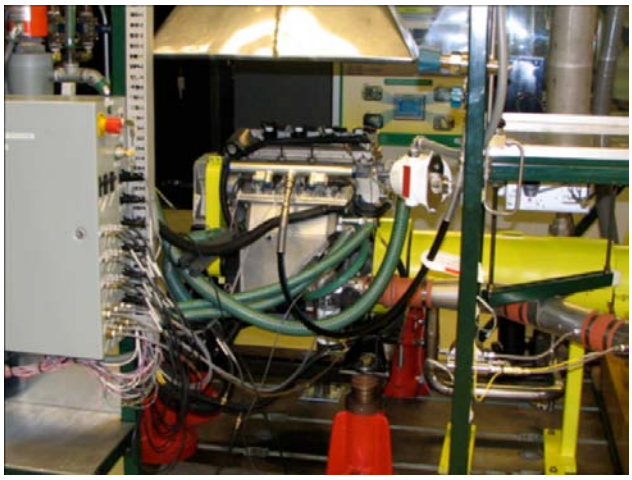

Figure 4: Combustion strategy development and calibration on engine dynamometer.

As they put the hydrogen engine through its paces with MATT, Argonne's researchers evaluated the fuel economy and emissions generated by different combustion strategies (Figure 4). Lohse-Busch and his colleagues eventually arrived at the optimal variable air-fuel ratio combustion strategy, which allows a hydrogen internal combustion engine to run efficiently and cleanly in a conventional vehicle.

According to Lohse-Busch, these hydrogen-burning combustion engines represent the "bridging technology to the hydrogen economy."

In the future, TTRDC researchers hope to use MATT to marry the hydrogen-burning internal combustion engine with a hybrid propulsion system. This approach, Lohse-Busch explained, would enable Argonne researchers to reap more benefits from both technologies.

"With the additional power supplied by a battery," he said, "we can supply the hydrogen engine with leaner fuel streams, enabling the engine to run more efficiently and cleanly."

Development and construction of MATT were funded by the Department of Energy's Office of Vehicle Technologies under Lee Slezak.

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Argonne Is Full of Energy (Research)

Argonne is among the most influential places in the world when it comes to energy, fuel and battery research.

According to *ScienceWatch*, an online newsletter tracking trends and performance in basic research, Argonne produces some of the most cited and influential scientific papers in the field.

With energy at the forefront of economic and political discussions, *ScienceWatch* recently identified the most cited research sources by evaluating the "Energy & Fuels" category in Thomson Reuters' Science Citation Index. The rankings are based on 94 specialty journals in this topic area that produced about 100,000 papers indexed between 1998 and 2008.

Khalil Amine

The article ranks Argonne 13th in the world in terms of citations, with a total of 2,438. Argonne ranks sixth in the world in citation impact, or citations per paper.

Khalil Amine, Argonne senior scientist and manager of the Advanced Battery Technology Group, ranks 11th on the list of most cited authors, with 41 papers that have been cited 773 times. His group has produced the most cited work in the battery field over the last decade.

"These rankings show that Argonne's work on new renewable energy is highly valued by the international community," Amine said.

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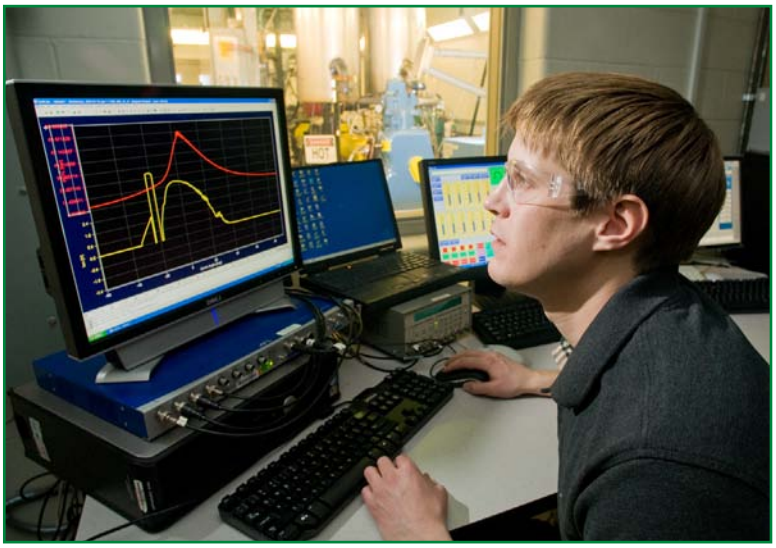
This Omnivore Likes a Variety of Fuels, not Foods

When it comes to fuel, Argonne's omnivorous engine doesn't play favorites. It can take down any blend of gasoline, ethanol, butanol and other types of spark-ignited fuel.



Michigan Technological University Ph.D. candidate Chris Cooney collects in-cylinder pressure and ion-sensing signals.

Though flexible-fuel vehicles have been around since Ford manufactured its Model T to run on both gasoline and ethanol, the omnivorous engine takes the concept to a whole new level. With this project, researchers are working to fashion an engine that allows spark-ignition vehicles to run more efficiently on ethanol and other next-generation alternative fuels.

"Just because an engine is compatible with different fuels doesn't mean that it has the ability to run at peak efficiency regardless of the fuel mixture," said Thomas Wallner, a mechanical engineer at Argonne. "That's where the benefits of the omnivorous engine lie."

The goal is to enable the omnivorous engine to calibrate itself so that it burns available fuel at maximum efficiency. This would be achieved through a suite of sensors in the combustion chamber and exhaust that tell the engine what kinds of fuels are used.

Wallner and his colleagues are also collecting ion-sensing signals for all the test fuels and blends to determine whether the signals can be used to optimize combustion, or even derive fuel composition.

"However, the ultimate goal is not to know what's in the tank, but to have it run as efficiently as possible on whatever comes down the fuel line," Wallner said. "This engine can run on pretty much any liquid fuel that can be ignited with a spark."

But Argonne engineers are not only concerned with what goes in the engine; they're also taking a close look at what comes out of the tailpipe.

This aspect of the project involves analyzing exhaust gases for a wide variety of fuels and fuel blends. Wallner pointed out that alcohol fuels are expected to show increased emissions of constituents that are

Argonne principal fuels engineer Steve McConnell refills the fuel cart of the omnivorous engine – for this particular test, with 100% ethanol.

currently not regulated, so they are measuring both regulated emissions like oxides of nitrogen, carbon monoxide and hydrocarbons, and several non-regulated emissions like aldehydes.

To help with this process, engineers are using a newly commissioned piece of equipment called the Fourier Transform Infrared Spectroscopy (FTIR), an optical measurement tool that can analyze up to 25 different exhaust components simultaneously.

Wallner and his fellow researchers recently completed a report, "Effects of Blending Gasoline With Ethanol and Butanol On Engine Efficiency Using a Direct-Injection, Spark-Ignited Engine," to be presented in May at the 2009 American Society of Mechanical Engineers' Spring Technical Conference in Milwaukee, Wisconsin.

They are currently working on two more reports which focus on the ion-sensing analysis and non-regulated emissions.

And there is still much work to be done on the omnivorous engine.

"We are just completing the baseline testing, which is meant to help us understand what the ion-sensing traces look like for different operation conditions and fuel blends," Wallner said. "This will be used to determine what processing is necessary to derive the information needed for real-time optimization."

The omnivorous engine research is funded by the Department of Energy's Office of Vehicle Technologies under Gurpreet Singh and Kevin Stork.

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Argonne research engineer Thomas Wallner adjusts the delay on an ion-sensing circuit used to get real-time combustion feedback.

New Tribology Center Opens its Doors

What do alternative fuel technology, artificial joints and military vehicles operating in the Middle East have in common?

They all stand to benefit from research being done by the Illinois Center for Advanced Tribology (ICAT), a virtual center formed by Argonne National Laboratory and three partnering universities: Northwestern University, University of Illinois at Urbana-Champaign and University of Illinois at Chicago.

Tribology is the study of interacting surfaces in relative motion. This includes the friction, lubrication and wear of things like bearings and gears, but also human beings and virtually everything else that moves.

"ICAT members bring together complementary and in some cases unique capabilities to resolve critical wear and lubrication issues in the development of advanced alternative energy technologies and biomedical implants and improve functionality and longevity of systems that operate in extreme environments," said George Fenske, manager of Argonne's tribology group.

Alternative Energy Technologies

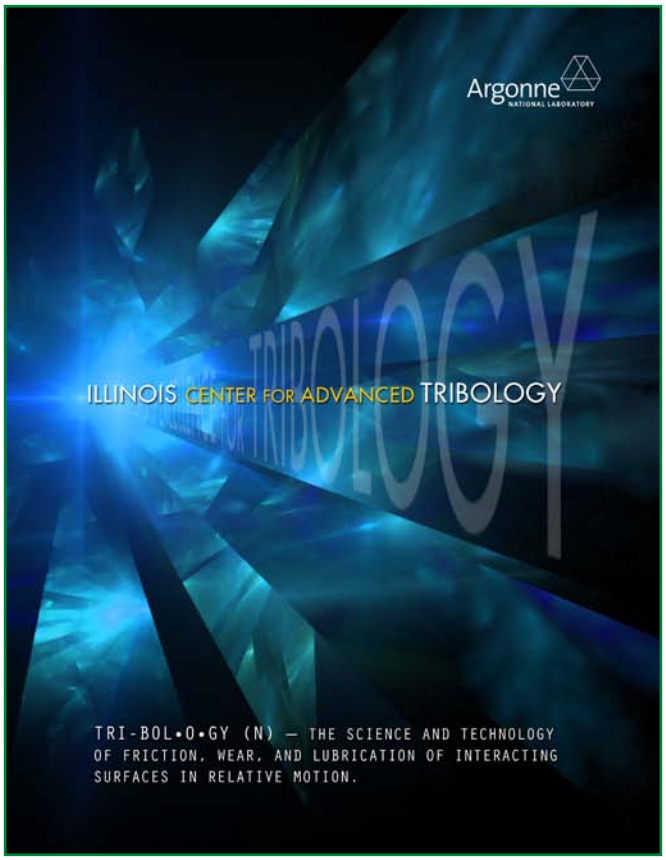
Our dependence on imported petroleum coupled with environmental concerns has created an urgent push to develop alternative fuels and alternative energy technologies. But these new technologies and vehicles bring an entirely new set of tribological issues for researchers to address.

"Biofuels, even E-85, can cause corrosion and wear to surfaces they come into contact with," said Jane Wang, a professor of mechanical engineering at Northwestern. "In the case of hydrogen powered vehicles, new lubricant formulas are needed for the smooth operation of moving parts since hydrogen fuel cells, which require a pure environment, prohibit the use of oil-based lubricants."

Health and BioTribology

In the biomedical field, ICAT researchers will work closely with medical institutions to develop replacement biomaterials with tribological behaviors similar to natural joints. Michael McNallan, a professor and associate dean in UIC's College of Engineering, said the goal is improve the durability and long-term health risks of replacement joints for more active patients.

"While current artificial joints have relatively good wear resistance, wear still occurs, and that is of particular concern when it comes to younger people who must rely on artificial joint implants for several decades," McNallan said. "We want to develop biomaterials with in-vivo tribological behaviors. Our goal is to help develop 'joints for life."



Cover of ICAT brochure. Brochure is available at www.transportation.anl.gov/pdfs/MM/520.pdf.

Extreme Tribology

Elevated temperatures, high or very low speeds and dirty, sandy environments pose significant challenges to the reliability and durability of critical tribological systems operating in these locales. This is especially true in the Middle East, where military vehicles being used were designed 20 to 30 years ago for use in mild climates. In these older vehicles, sand and extreme heat is causing premature failure as a result of poor lubricity.

"Thermal degradation of base fluids and additives are accelerated at high temperatures, and oil viscosity is poor at high temperatures and further aggravated by the presence of sand," said Andreas Polycarpou, a professor in University of Illinois at Urbana-Champaign's Department of Mechanical Science and Engineering. "So one of the many innovations we plan to make is the development of self-healing surfaces; such technology would be highly desirable for extreme-condition applications."

Working Together

With the formation of ICAT, these important issues are being taken on by a collaboration that pulls together the skills, talents and unique facilities of Argonne and the three partnering universities. The center will solicit research funds from their parent organizations and private and industrial sources.

Fenske also pointed out that ICAT would allow the partner organizations to respond more quickly to requests for research proposals because they will not have to develop work agreements for each request. The organizations will also respond to solicitations from the State of Illinois and federal agencies such as the Department of Energy, the Department of Defense, the National Science Foundation, the National Institutes of Health and the Department of Agriculture.

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Facility Spotlight

The Tribology Center's CemeCon

Friction in moving engine components (e.g., camshafts, pistons) is a significant source of parasitic energy loss that wastes fuel. In addition, premature wear of a part incurs its own replacement energy costs.

To improve the performance of a component that has high friction or wears out prematurely (e.g., metal, ceramic or polymer), a coating can be applied to the surface to reduce friction or make it more wear-resistant, or both.

Argonne's CemeCon plasma vapor deposition (PVD) system shown at right is used to deposit coatings onto manufactured parts. The new and novel coatings enhance the durability and/or efficiency of transportation systems.

CemeCon coating chamber

One Argonne coating discovery based on hydrogenated carbon, Near Frictionless Carbon, received an R&D 100 Award in 1998. Researchers Ali Erdemir, George Fenske, and Osman Eryilmaz found that this unique material can be deposited on a wide variety of surfaces and possesses low friction under many conditions. It is several times harder than steel and is wear-resistant. The coating is deposited from a plasma using carbon-containing gases. This technology is currently being considered for licensing by several companies.

A different coating material, termed "super-hard nanocomposite," makes use of the strengthening effect of nano-sized grains to produce a surface many times harder than steel, which has superior wear properties. This is produced using reactive sputter deposition.

The carbon and super-hard coatings are typically one micrometer in thickness, and thus do not harm the tolerance or accuracy of a part.

The CemeCon PVD system is part of Argonne's Tribology Laboratory. For more information and an online tour, visit www.transportation.anl.gov/facilities/tribology.html.

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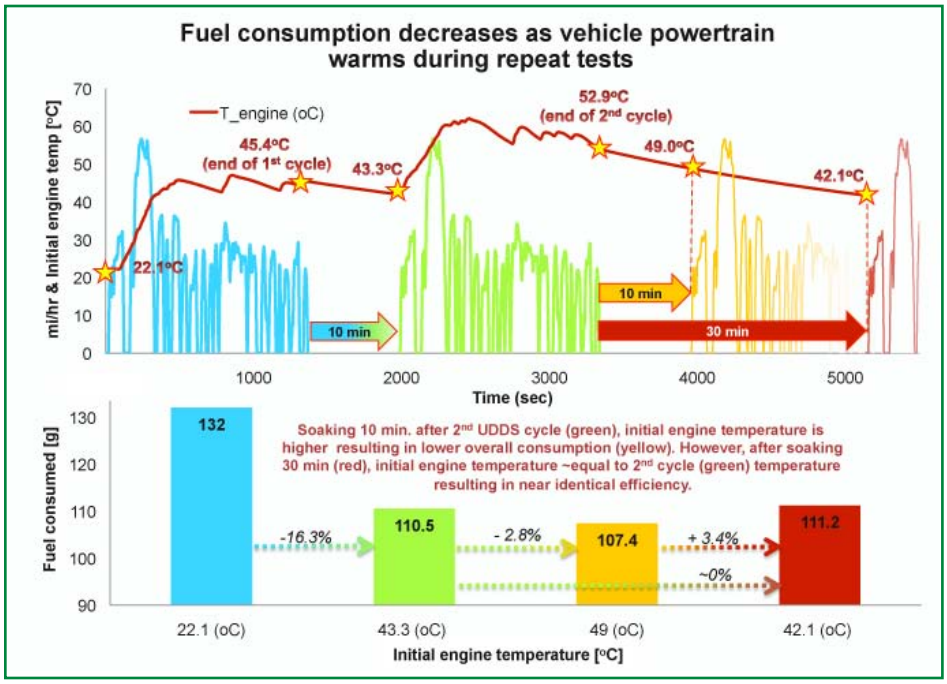
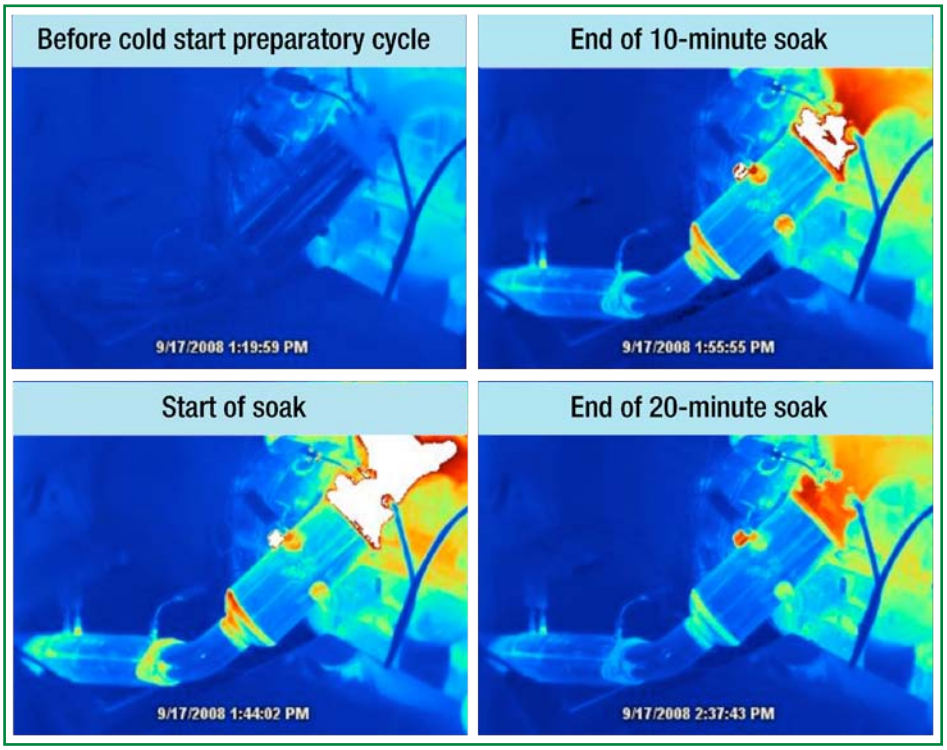
Real-World Temperature Effects on Plug-in Hybrid Electric Vehicles

Forrest Jehlik and his colleagues at Argonne's Transportation Technology R&D Center are studying the effects of temperature on powertrains in plug-in hybrid electric vehicles (PHEVs) to discover the thermal effects on fuel efficiency.

Testing PHEVs over standardized and real-world drive cycles shows relatively large differences between ambient cold starts and hot starts. While testing various PHEVs' efficiencies, losses of 25-40% efficiency were observed when starting the engines at 20°C and allowing them to achieve optimal hot operating temperatures. Understanding the effect temperature variations have on overall fuel economy numbers due to soak times is pertinent in defining proper industry measurement standards. (*Soak time* is defined as the duration of time in which the vehicle's engine is not operating and which precedes a successful vehicle start.)



Modeled engine fuel consumed as a function of soak time between UDDS cycles. (UDDS stands for Urban Dynamometer Driving Schedule, and refers to a U.S. Environmental Protection Agency-mandated dynamometer test that represents city driving conditions. It is used for light-duty vehicle testing.) Three back-to-back cycles with (1) 10/10-minute soak times, and (2) 10/30-minute soak times. Colors of vehicle speed traces correspond to fuel consumed. Stars denote beginning and end of drive cycles.



Combined with methods of predicting the engine thermal state from its initial temperature, these researchers have been able to accurately predict the fuel efficiency of a PHEV drive cycle from a cold engine start-up to its fully operational temperature.

Experiments

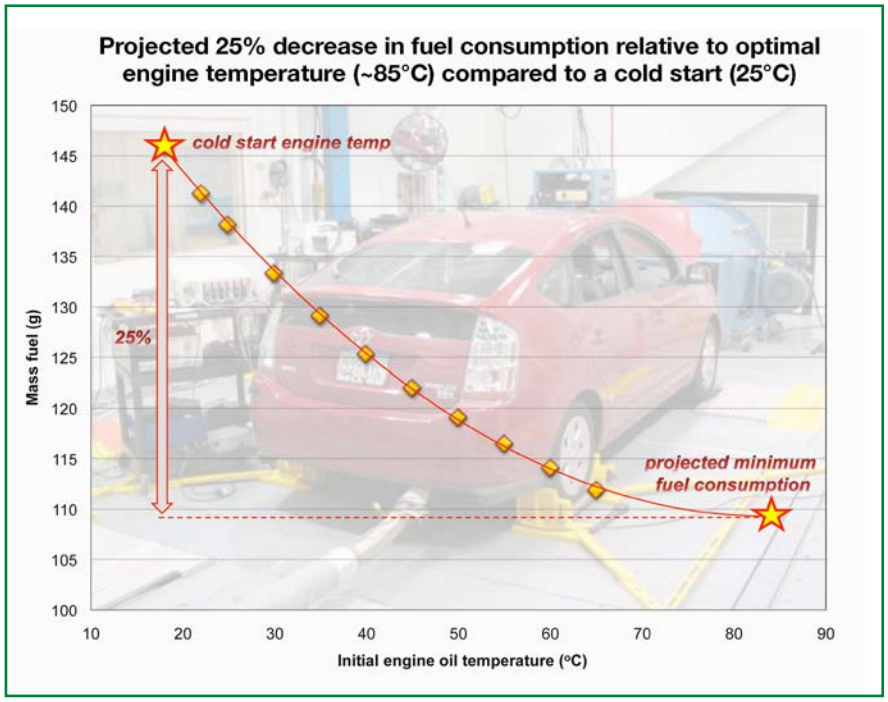
Studies using surface methodology techniques were performed on a number of vehicles of varying architecture.

Engine surface temperature collected during a soak time sensitivity study using Argonne's Modular Automotive Technology Testbed (see page 2 for more on MATT). Pictures quantify cooling that occurs in powertrains during engine-off conditions. Data collected by Henning Lohse-Busch.

Prius Study Results

In one study, Jehlik and his colleagues analyzed the total fuel efficiency loss as a function of engine temperature using a 2007 Toyota Prius Hymotion PHEV conversion. Results of their analysis showed that

- As expected, engine efficiency significantly increases with increasing engine temperature.
- An initial cold start enrichment spike accounts for a 3% fuel efficiency decrease. Much greater losses follow cold start enrichment.
- In the range of 25-60˚ C, each 5˚ C increase in engine temperature decreases fuel consumption by 1.9-3.2%. Fuel consumption decreases as temperature increases, eventually reaching a projected minimum at approximately 85˚ C. For the Prius, ten-minute soak times may result in ~5˚ C variations in temperature as a function of powertrain temperature.



Modeled UDDS cycle fuel consumption as a function of initial engine temperature; optimum value is projected from response-modeled results. Stars denote the difference in fuel consumption over the UDDS cycle from ambient cold start to the modeled projected minimum fuel consumption.

- Losses dues to electric components, rolling and transaxles are minimal as compared to engine and transmission thermal losses.
- The projected optimal engine temperature is ~25% more efficient than a 22˚ C ambient cold start. Cold starts at lower temperatures would lead to greater efficiency losses.

It is the ultimate goal to integrate this methodology into vehicle systems modeling and better quantify the thermal effects on vehicle fuel consumption. Ultimately, the results from this methodology, and following studies, may result in more efficient engineered thermal management systems for powertrains of PHEVs. This would result in significant fuel consumption reductions.

A complete copy of this conference paper can be obtained by ordering it from SAE at https://shop.sae.org/congress/2008/. Select "Technical Papers," and then "Systems and Components."

This research was supported by DOE's Office of Vehicle Technologies under the direction of Lee Slezak.

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GREET 1.8c Available Now

On March 23, 2009, the newest version of GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) was released by Argonne.

The new features of Greet 1.8c include:

- Detailed simulation capabilities of plug-in hybrid electric vehicles.
- Updated fuel economies of baseline and alternative vehicle technologies from the Energy Information Administration and U.S. Environmental Protection Agency publications as well as simulated fuel economy results from Argonne's PSAT model.
- Updated projections of United States, California, and northeastern U.S. electricity generation mixes based on EIA's Annual Energy Outlook 2009.

For more details on the new version, visit http://www.transportation.anl.gov/modeling_simulation/GREET/pdfs/greet1_8c_memo.pdf.

GREET can be downloaded FREE at http://www.transportation.anl.gov/modeling_simulation/GREET/index.html.

Argonne Engineer Helps Assess NASA's Energy Storage Capabilities

Jim Miller has done some pretty *far out* research on batteries and fuel cells here at Argonne, but one of his recent endeavors was really *out of this world*.

Jim Miller

Miller, a senior electrochemical engineer and director of Argonne's Electrochemical Technology Program, was part of a National Research Council (NRC) committee formed to assess space exploration technology at National Aeronautics and Space Administration (NASA). The NRC committee recruited Miller for his expertise in advanced batteries and fuel cells.

Energy storage is a critical piece of NASA's technology program for a number of reasons: space shuttles use fuel cells for on-board electric power, astronauts have batteries on their spacesuits during spacewalks, and NASA's use of solar power for long duration missions on the Moon or Mars would require significant energy storage.

To evaluate NASA's existing technology program, committee members visited sites like the Johnson Space Center (JSC) in Houston and the Glenn Research Center (GRC) in Cleveland. From the Supersonic Wind Tunnels at GRC to Mission Control Center at JSC, Miller was exposed to some fascinating things during the assessment process.

"I really didn't know all that much about NASA before this," Miller said. "So I found it to be an extremely interesting experience."

The NRC study began as a directive from Congress, which required that NASA conduct an independent assessment of its Exploration Technology Development Program (ETDP) and how well it is aligned with the objectives of the Vision for Space Exploration (VSE). Former President George W. Bush announced the VSE in 2004, instructing NASA to "extend human presence across the solar system, starting with a human return to the Moon by year 2020, in preparation for human exploration of Mars and other destinations."

The committee report, "A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program," found that NASA's ETDP is making progress toward its stated goals, but that there are significant constraints limiting the technology program's ability to accomplish these goals. The constraints include a limited budget, the still dynamic nature of the Constellation Program requirements, the aggressive time scale of early technology deliverables, and the desire to fully employ the NASA workforce.

In terms of energy storage, the committee found that NASA has very good facilities for both battery and fuel cell research and testing, and that their efforts are well aligned with the VSE.

The prototype for NASA's Lunar Electric Rover is a plug-in electric vehicle with a 125 W-hr/Kg lithium-ion battery. NASA researchers are working to meet NASA requirements that the rover have a 200 W-hr/Kg battery. Photo courtesy of Regan Geeseman, www.nasa.gov.

But with a constant need for innovative and improved energy solutions, Miller believes that Argonne's battery research could also be beneficial to NASA in the future.

"Research being done in Argonne's advanced lithium-ion battery program could very well find its way into future applications in the space program," Miller said. "In fact, I'd be disappointed if it didn't."

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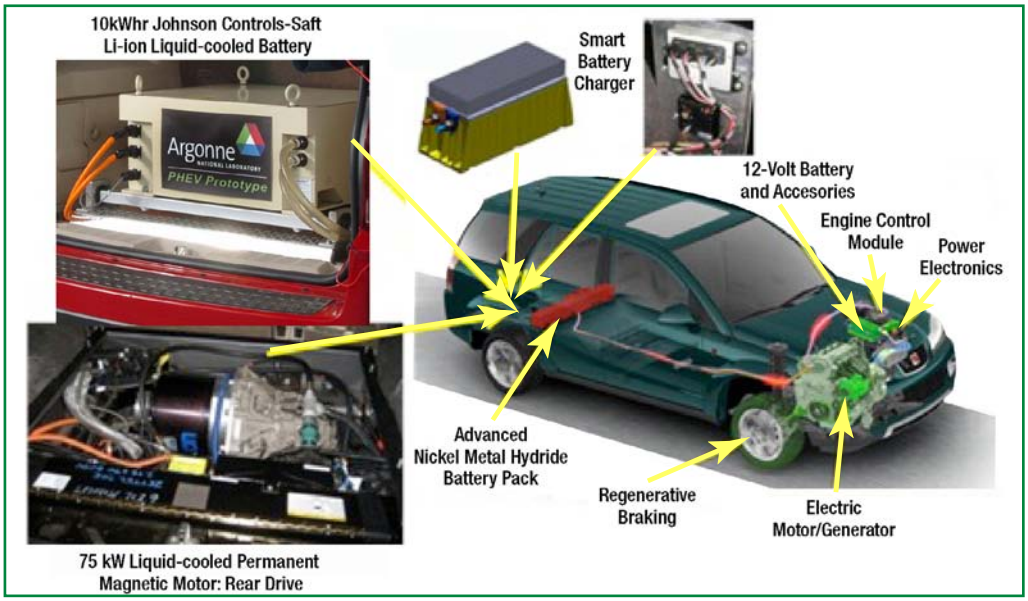
Drivetrain Electrification Components Also 'Drive' Price

The concept of hybrid and electric automobiles is now old news, but these alternative fuel vehicles are still in the minority on American roads.

The most significant factor limiting the commercial success of these next-generation vehicles is not a technological barrier; it's the price tag.

"The technology for electric drives accomplishes the performance needs for electrically driven vehicles, but not the cost targets to make them competitive with conventional vehicles," said Ted Bohn, an electrical engineer in Argonne's Transportation Technology R&D Center.



Through-the-road (TTR) parallel hybrid showing placement of component technologies.

That's where Argonne's component technology development program comes into play. Bohn and other researchers In Argonne's Advanced Powertrain Research Facility are currently looking at the electric drivetrain components to improve efficiency and lower manufacturing costs, so that hybrid and electric vehicles can become more affordable to the general public.

Energy storage systems, power electronics, electric machines and gearboxes and control systems are the four main components used in drivetrain electrification. Here are a few of the projects Argonne is currently working on to increase performance and reduce costs:

Through-the-Road Parallel Hybrid (TTR). This in-house plug-in electric hybrid vehicle (PHEV) development platform was created so that high-level vehicle control strategies can be evaluated. In addition to the features shown in the diagram above, the TTR test vehicle has axle torque sensors in the front and rear to measure power "through-the-road."

Energy Storage System (ESS) Components. Argonne has partnered with Maxwell Technologies to investigate the benefits of combining high-power density ultracapacitors with high-energy density lithium-ion batteries. This combination potentially reduces the net ESS cost and provides full acceleration and braking power at low temperatures or high battery state of charge.

Electric Machine/Gearbox Components. A 55 kilowatt peak/30 kilowatt continuous hybrid electric prototype machine has been designed that meets the performance and cost targets established by DOE's Office of Vehicle Technologies by minimizing high frequency losses in the motor. This machine focuses on low material cost, low rotor losses, 95% efficiency at 20% load, and constant power from 2,800-14,000 rpm, with 105°C coolant.

Bohn pointed out that the Department of Energy's FreedomCAR and Fuel Partnership's cost targets could also help lower the price tag of hybrid and electric vehicles. By 2015, FreedomCAR sets an electric drive system cost goal of $12/kW for a 55kW peak rated motor.

"If this goal could be met, it would bring the cost of building a hybrid vehicle much closer to that of a conventional engine," Bohn said.

Another factor that could contribute to reducing manufacturing costs is gas prices.

"If fuel prices rise again as the economy recovers, the incentive to reduce fuel consumption, driven by fuel cost, will also enable higher volumes of hybrid vehicles to be sold which, via economies of scale, will reduce the cost of hybrid vehicle components," Bohn said.

This research was funded by the Department of Energy's Office of Vehicle Technologies under Lee Slezak.

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Student Innovators Driven by the Environment

Student engineers participating in *EcoCAR: The NeXt Challenge* recently completed a major milestone in their 3-year quest to win the competition by unveiling their vehicle architectures. Now more than halfway through the first year of the program, the students' 17 unique designs provide a glimpse into the future of green vehicle technology solutions and embrace innovations ranging from plug-in hydrogen fuel cells to all-electric vehicles.

EcoCAR, which is sponsored by the U.S. Department of Energy (DOE) and General Motors (GM), as well as the Government of Canada, the California Air Resources Board and more than two dozen other government and industry leaders, provides invaluable experience and training to the next generation of engineers developing future green vehicle technology solutions. Argonne National Laboratory provides competition management, team evaluation, and technical and logistical support. The competition challenges 17 universities across North America to explore solutions to achieve improved fuel economy and reduce greenhouse gas emissions, while retaining the performance and consumer appeal of a 2009 Saturn VUE.

Saturn Vue EcoCAR

The student teams have worked tirelessly to develop the advanced technology vehicle designs that will not only meet the competition criteria, but also represent their vision for their '*EcoCAR*' of the future. Students were encouraged to explore a variety of solutions including hybrid, plug-in hybrid, fuel cell, electric and extended-range electric vehicles. The 17 *EcoCAR* designs selected are as follows:

- **Extended-Range Electric Vehicles (EREV)** — Eight of the *EcoCAR* teams chose to design extended-range electric vehicles, which, like GM's Chevy Volt, demonstrate full performance with an electric powertrain for all-electric driving and an optimized combustion engine that can extend the range of the vehicle with its on-board fuel storage.
- **Plug-In Hybrid Electric Vehicles (PHEV)** — Six teams have designed plug-in hybrid electric vehicles that include a large lithium-ion battery. The battery can be recharged by plugging into the wall and the vehicle may operate without using the engine at all. Once the plug-in range of the battery is depleted the vehicle can still operate as a regular hybrid.
- **Full-Function Electric Vehicle (FFEV)** — Only one team chose to design a full-function electric vehicle, which has an all-electric motor powering its drive train and has over 100 miles of range. It stores energy in batteries that can be charged using a home electrical outlet.
- **Fuel Cell Plug-In Hybrid Electric Vehicle (FCPHEV)** — Two teams have designed a fuel cell plug-in hybrid vehicle which uses an onboard hydrogen fuel cell to either propel the vehicle or recharge a battery pack. The battery pack can be charged using a home electrical outlet. The FCPHEV uses significant battery energy before relying on the fuel cell to extend the range of the vehicle.

While each of the 17 *EcoCAR* designs is unique, there are common attributes including:

- All of the vehicles have some plug-in capability, which can significantly reduce on-road petroleum consumption.
- All of the designs use state-of-the-art lithium-ion battery technology, so the vehicles are able to store more electric energy in smaller, lighter packages.
- All of the vehicles use a renewable energy source that displaces petroleum consumption, which significantly reduces the amount of greenhouse gases emitted from the vehicles tailpipes.
- All of the *EcoCAR* team architectures must retain the safety and real-world performance characteristics of production vehicles that consumers demand.

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Water Use in the Production of Biofuels and Gasoline

Just as water is a vital component of biological processes, it is also essential to producing both biofuels and gasoline. In fact, water has even become a key feature of existing energy projects, and a potential issue in new ones. Argonne researcher Michael Wang and his colleagues at the Transportation Technology R&D Center recently completed a study that looks at the water used for the production of energy feedstocks and fuels from the perspective of the fuels' lifecycles, including resource extraction, feedstock transportation, fuel production, fuel transportation and operation of a vehicle on the fuel.

Their work focused on two major steps of fuel lifecycles: feedstock production (farming or oil recovery) and fuel processing/production (ethanol production or oil refining). Researchers looked at the consumption of irrigation water, oil-well injection water and process water for five fuel pathways: bioethanol from corn, ethanol from cellulosic feedstocks, gasoline from Canadian oil sands, Saudi Arabian crude and U.S. conventional crude from onshore wells.

Their analysis found that water consumption for feedstock and fuel production varies considerably by type of feedstock, soil and climactic condition and production technology for bioethanol; and by age of oil well, recovery technology, and extent of produced water re-injection and steam recycling for petroleum gasoline. There are significant regional differences, however, particularly for corn production. A summary of consumptive water use for the fuels analyzed in this study is presented in Table 1.

The study noted that cumulative impacts are a particularly critical issue for fuel development. Given the rapid development of both oil sands and biofuel globally, it is conceivable that the sustainability of water resources may be affected more by impacts accumulating over time and across numerous nearby projects, than by average gallons-of-water-used-per-gallon-of-fuel-produced as examined in this study. This possibility has important policy implications and suggests that additional studies, including site-specific analyses, are needed to better understand the ramifications of energy development.

The study concludes that conservation measures can reduce water consumption and achieve sustainable bioethanol and gasoline production. Specifically:

- Improved water management is needed for corn irrigation, particularly in those areas where water is scarce.

Table 1. Consumptive Freshwater Use for Ethanol and Petroleum Gasoline Production

Fuel (feedstock)	Net water consumed[a]	Major factors affecting water use
Corn ethanol	10–324 gal/gal ethanol[d]	Regional variation caused by irrigation requirements due to climate and soil types
Switchgrass ethanol	1.0–9.8 gal/gal ethanol[d]	Production technology
Gasoline (U.S. conventional crude)[b]	3.4–6.6 gal/gal gasoline	Age of oil well, production technology, and degree of produced water recycle
Gasoline (Saudi conventional crude)	2.8–5.8 gal/gal gasoline	Same as above
Gasoline (Canadian oil sands)[c]	2.6–6.2 gal/gal gasoline	Geologic formation, production technology

[a] In gal of water per gal of fuel specified.
[b] PADD II, III, and V combined.
[c] Including thermal recovery, upgrading, and refining.
[d] All water used in ethanol conversion is allocated to the ethanol product.

- Cellulosic feedstocks should be grown in their native habitat to reduce or eliminate irrigation.
- Groundwater management is especially critical in arid regions, and in locations with high concentrations of biofuel or oil production facilities.
- Steam condensate reuse, process water recycling and water-conserving process modifications using existing commercial technologies should be implemented wherever possible.
- For cellulosic ethanol facilities, a process design optimized to reduce water use should be encouraged.
- For oil recovery, produced water re-injection should be used to the maximum extent possible.

This work is supported by the U.S. Department of Energy's Office of Biomass under Zia Haq.

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Don Hillebrand is quoted in "The Auto Show Goes On," a February 12, 2009, article in *The Daily Herald*. View the story online at www.dailyherald.com/story/?id=271478.

Chris Marshall is featured in the February 20, 2009, article, "Catalyst Knocks Out Smog Maker," in *ScienceNews*. Check it out at www.sciencenews.org/view/generic/id/41073/description/Catalyst_knocks_out_a_smog_maker.

The Southtown Star spoke with **Don Hillebrand** and **Ted Bohn** for "Argonne Scientists in the Driver's Seat for Hybrid Demand," a February 26, 2009, article about Argonne's plug-in hybrid research. Read the article at www.southtownstar.com/news/1450506,022609hybrid.article#.

Jim Miller is quoted in the article, "Worldwide Race to Make Better Batteries," in the January 22, 2009, edition of *The Christian Science Monitor*. View it at http://features.csmonitor.com/innovation/2009/01/22/worldwide-race-to-make-better-batteries/.

The New York Times interviewed **Michael Duoba** for the article, "Cranking the Volt to 100 M.P.G.," on November 28, 2008. Read the article online at www.nytimes.com/2008/11/16/automobiles/16STICKER.html?scp=1&sq=cranking%20the%20volt&st=cse.

Michael Duoba is quoted in the Bloomberg article, "GM Claims 100 Miles-a-Gallon Volt 'Bragging Rights,'" on September 26, 2008. View the story at www.bloomberg.com/apps/news?pid=newsarchive&sid=aejB7m2yUt24.

FOX Business spoke with **Michael Duoba** for its December 3, 2008 report, "Can the Volt save GM?" For a link to the video, visit the Press Coverage webpage at www.transportation.anl.gov/media_center/press_coverage_archive/2008_press.html.

Ted Bohn and **Dan Santini** were interviewed for "For Kids: Ready, Unplug, Drive," an article geared at explaining hybrid vehicles to kids in the October 28, 2008, edition of *ScienceNews*. Read the story at www.sciencenews.org/view/generic/id/38043/title/FOR_KIDS_Ready,_unplug,_drive.

Bassam Jody is quoted in the article, "Auto Shredder Residue Recycling Researched," in the October 2008 edition of the *American Recycler*. View it online at www.americanrecycler.com/1008/auto.shtml#cover.

Michael Thackeray was interviewed by *Newsweek* for the November 22, 2008, article "Now We're Cooking With… Batteries." Check out the full story at www.newsweek.com/id/170341.

Di-Jia Liu is quoted in the article, "Carbon Catalyst Could Herald Cut-Price Fuel Cells," in the February 6, 2009, edition of *New Scientist*. Read it at www.newscientist.com/article/dn16547-carbon-catalyst-could-herald-cutprice-fuel-cells.html.

FASTRAX

Ted Bohn and **Dan Santini** were invited to serve on an advisory board to assist Iowa State University's research on emerging interdependencies between national energy and transportation infrastructure. Because plug-in hybrid electric vehicles (PHEVs) constitute a major link between the two infrastructures, the university, which received a National Science Foundation grant for this project, reached out to the Argonne researchers for their expertise. Bohn and Santini join a diverse external advisory board to provide insight on PHEVs and their capabilities, limitations and projected evolution.

Forrest Jehlik was a guest speaker at the University of Wisconsin-Madison Department of Mechanical Engineering's Lindbergh Lecture Series on March 12, 2009. He spoke on "Methodology and Analysis of Plug-In Hybrid Powertrain Fuel Efficiency as a Function of Engine Thermal State." This presentation summarized some of the thermal analysis and methodologies developed at Argonne's Advanced Powertrain Research Facility to characterize plug-in vehicle efficiency losses as a function of operational temperature. Jehlik also presented an overview of Argonne's plug-in and advanced vehicle research facilities and capabilities.

Jim Miller participated on the National Research Council's Committee to Review NASA's Exploration Technology Development Program, and co-authored the committee's report "A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program." Among other things, the report addresses surface mobility for lunar and Mars environments.

Linda Gaines presented "Lithium-ion Batteries: Possible Material Demand Issues" at the 13th International Battery Materials Recycling Seminar and Exhibit at Fort Lauderdale, Florida in March 2009.

Kyeong Lee received a certificate of appreciation for outstanding service from the American Chemical Society (ACS) for his participation in the 2008 Fall ACS National Meeting and Exposition. Lee served as chair, organizer and paper presenter for a symposium entitled "Fine Particulate (PM2.5) Formation and Emissions from Fuel Combustion," which was held August 21, 2008, in Philadelphia, PA.

Khalil Amine won the 2009 Award for Excellence in Technology Transfer, an honor presented annually by the Federal Laboratory Consortium for Technology Transfer, for his work "Lithium Titanium Oxide Spinel Anode System for High-Power Lithium-Ion Batteries." The award recognizes outstanding work in the process of transferring a technology developed by a federal laboratory to the commercial marketplace.

Renée Nault and **Sana Ann Sandler** won two awards of Excellence in Technical Art from the Chicago Chapter of the Society for Technical Communication for creating the displays, "Transportation Research and Analysis Computing Center: Exhibit" and "Enabling Deployment of Biobased Fuels and Products." Nault and Sandler also received an award of Merit in Technical Marketing Support for their work on "Illinois Center for Advanced Tribology" brochure.

Renée Nault, **Sana Ann Sandler**, and **Cindi Andersen** were honored with an award of Excellence in Technical Publications from the Chicago Chapter of the Society for Technical Communication for "Transportation Research and Analysis Computing Center: Fact Sheets."

Michael Wang and **Andrew Burnham** are featured in the new Department of Energy (DOE) book "A Decade of Discovery," highlighting breakthroughs in science and engineering by national laboratories. The researchers appear on pages 36-37 in a section called "Mapping Energy from the Source: From Your Car's Tailpipe and Beyond" dedicated to Argonne's Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) model.

Argonne's **Through-the-Road hybrid vehicle** (TTR) was on display at the Washington Auto Show at the Walter E. Washington Convention Center, February 4-8, 2009, in Washington, D.C. The TTR was featured in the combined U.S. Department of Energy, Environmental Protection Agency, and Department of Transportation exhibit booth that displayed advanced vehicle technologies that are safe, clean, and efficient.

Larry Johnson was recently appointed the Alternate Delegate to the International Energy Agency's Advanced Motor Fuels International Agreement (AMF). The AMF is an international forum to promote cleaner and more efficient fuels for transportation.

Glenn Keller and the French Trade Mission of Chicago organized a visit that brought French auto industry representatives to the Argonne Transportation Technology R&D Center on November 18, 2008. Information on technology opportunities for hybrid and electric vehicles was shared and discussed. As evidenced by the meeting, France is taking a different approach to green transportation, with a focus on the development of micro-hybrid and electric vehicles for limited urban use that employ lowest-cost electric batteries.

Kentucky Governor Steve Beshear, members of the Kentucky government and Kentucky university officials visited **Argonne's battery materials and vehicle systems groups** on November 5, 2008. During their stay, **Glenn Keller** led tours of Argonne's facilities, as the visitors explored opportunities for collaboration in sustainable energy transportation.

Larry Johnson hosted the Directors from the United States Council for Automotive Research (USCAR), the Department of Energy's partner in the FreedomCAR and Fuel Partnership, when they visited Argonne's Transportation Technology R&D Center on October 30 and 31, 2008. Argonne's innovative projects, facilities and capabilities were highlighted throughout the two days of meetings, tours and presentations. The visitors included Ann Schlenker from Chrysler; John Sakioka from Ford; Bill Peirce and George Andrews from GM; and Don Walkowicz, Mike Martin and Natalie Olds from USCAR.

Bassam Jody and Argonne National Laboratory's work in plastic recycling were recognized by the Department of Energy as a success story in the article, "Recovering Plastics from Retired Vehicles." The article is the first in a series of success stories being prepared for the DOE's Office of Vehicle Technologies.

The work of **Neeraj Shidore**, **Thomas Wallner**, **Henning Lohse-Busch**, **Aymeric Rousseau** and the **PSAT team** was recognized in the FreedomCAR and Fuel Partnership 2008 Highlights of Technical Accomplishments. Shidore received accolades for his project investigating the cold ambient effects on lithium-ion battery performance. Wallner, Lohse-Busch, Rosseau and the PSAT team were recognized for their work with hydrogen, both on engines and vehicle-level simulation.

Ted Bohn, **Glenn Keller**, **Sylvain Pagerit** and **Jim Miller** represented Argonne at the 2008 Electric Drive Transportation Association Conference & Exposition in Washington D.C. from December 2-4, 2008. Keller, Pagerit and Miller were all speakers at the conference, while Bohn helped organize Argonne's participation and its informational booth at the event.

PUTTING ARGONNE'S RESOURCES TO WORK FOR YOU

Industrial technology development is an important way for the national laboratories to transfer the benefits of publicly funded research to industry to help strengthen the nation's technology base. The stories highlighted in this issue of TransForum represent some of the ways Argonne works with the transportation industry to improve processes, create products and markets, and lead the way to cost-effective transportation solutions, which in turn lead to a healthier economic future.

By working with Argonne through various types of cost-sharing arrangements, companies can jump-start their efforts to develop the next generation of transportation technologies without shouldering the often prohibitive cost of initial R&D alone. Argonne has participated in dozens of these partnerships and has even been involved in helping to launch start-up companies based on the products and technologies developed here.

If working with world-class scientists and engineers, having access to state-of-the-art user facilities and resources, and leveraging your company's own capabilities sound like good business opportunities to you, please contact our Office of Technology Transfer and see how we can put our resources to work for you.

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